Apparatus for measuring conductivity

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Abstract of **GB2093192**

Apparatus for measuring conductivity of a liquid comprises insulating conduit in the form of one or more closed loops with spaced inlet and outlet ports 6, 7 to enable liquid to flow through the conduit, and at least one input transformer core 10 and at least one output transformer core 11 inductively coupled by the closed loops, the conduit configuration and positioning of the transformer cores being mutually arranged such that when the conduit is full of conducting liquid and alternating current is applied to the windings of the input transformer, the potentials induced at the inlet and outlet ports are the same. This apparatus can be connected into conducting pipework of a chemical plant without incurring errors through spurious ground loops through the pipework.

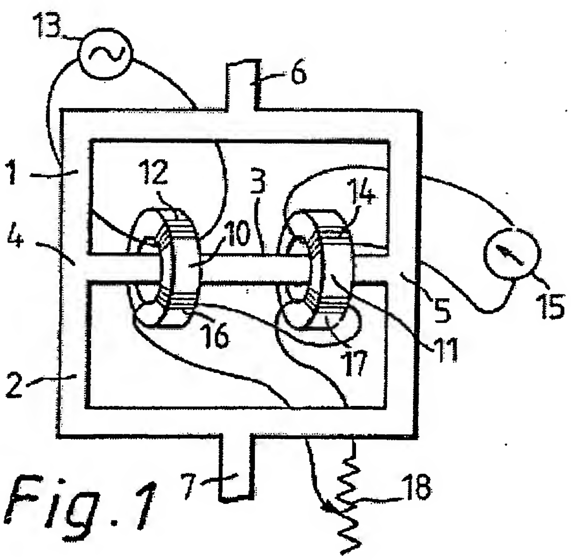

Fig.1

Apparatus for measuring conductivity

Description of **GB2093192**

SPECIFICATION
Apparatus for measuring conductivity
The invention relates to the measurement of liquid conductivity, and especially (though not necessarily) to apparatus suitable for measuring liquid conductivity on chemical plants.

During a continuous manufacture of chemicals, it is desirable to be able to determine the concentration of reactants or byproducts at various stages in order to monitor the progress of the manufacturing process. With some liquid mixtures and slurries, changes in composition are accompanied by significant changes in conductivity. Measuring techniques in which spaced electrodes are placed in contact with the liquids, tend to be unsuitable for prolonged continuous measurement due, for example, to deposition of electrolytic corrosion products on the electrodes or the generation of insulating layers of gas caused by electrolysis of the liquid. Other factors unconnected with the electrolysis, such as chemical corrosion, scaling or deposition of silt on the electrodes, can also effect very markedly the conductance values as measured using electrodes in direct contact with the liquids.

It was proposed in British Specification No. 695058 to measure the conductivity of a liquid without direct electrode contact, by an apparatus comprising an insulating tube in the configuration of a closed loop to be filled with the liquid, the loop being inductively linked with two transformer cores one of which carries primary windings adapted to be supplied with alternating current and the other of which carries secondary windings connected to a measuring instrument calibrated to indicate the conductivity of the liquid. Since then various refinements have been proposed, such as the Wayne Kerr bridge described in British Patent Specification 831692, and apparatus for such inductive conductance measurements have been manufactured commercially.

However, we found that when we used such inductive apparatus on our chemical plants for continuous monitoring of liquid conductivities, with the loop of insulating conduit connected to the plant pipework viainlet and outlet ports, variable intermittent errors were found to occur. From our investigations, it appeared that when an alternating current was passed through the primary windings, there was induced in the liquid a potential difference across the ports. Where the pipework was earthed conducting material, it provided a ground loop as an alternative conductor to the liquid. Had this been constant, it could have been calibrated out. However, we found that the effect was variable, probably because the liquid/pipework interface was acting like a liquid/electrode interface and giving corresponding problems.

According to the present invention, apparatus for measuring the conductivity of a liquid comprises insulating conduit in the form of one or more closed loops with spaced inlet and outlet ports to enable liquid to flow through the conduit, at least one input transformer core carrying primary windings for receiving alternating current and at least one output transformer core carrying secondary windings, the input and output transformer cores being inductively coupled by the one or more closed loops, and the configuration of the conduit and the positioning of the transformer cores with respect to the inlet and outlet ports being mutually arranged such that when the conduit is full of conducting liquid and an alternating current is applied to the primary windings of the input transformer, the potential thereby induced in the liquid at the inlet port is substantially equal to that induced at the outlet port.

The manner of operation of the present apparatus is essentially the same as that of the prior art referred to above in so far as an alternating current is passed through the primary windings of the input transformer to induce a current in the liquid flowing through the conduit. This in turn induces a further alternating current in the secondary windings of the output transformer, and the conductance of the liquid in the conduit can be evaluated, for example, by direct measurement of this further induced current or by balancing it against an opposing current induced by a reference circuit of known conductance in a bridge network. The conductivity of the liquid can then be obtained in known manner either by calculation from a knowledge of the loop dimensions or by calibration using liquids of known conductivity.Thus the one or more liquid loops serve as secondary windings on the input transformer core and as primary windings on the output transformer core in a manner analogous to the liquid loop of the prior art. But by arranging the conduit and cores to ensure that the potentials at the ports remain the same in accordance with the present invention, all the induced current must be carried between the cores by the liquid, and variable losses due to ground loops through metallic plant may be avoided.

There are various conduit configurations and associated positions of input transformer cores which will induce equal potentials at the two ports. In one species of such apparatus, the conduit configuration

comprises two closed loops, each having a portion common to both loops with the remaining portions exclusive, the exclusive portions being in liquid communication with the common portion through their junctions at both ends of the common portion, the inlet port being in the exclusive portion of one loop and the outlet port being at an equipotential position in the exclusive portion of the other loop.

A preferred apparatus of such two loop configurations is one having an input transformer core inductively linked to the common portion of the two loops. The potential at any position in each loop is then a function of the ratio of the conductance between that position and one junction, to that between the same position and the other junction. Positions of equal potential occur where the ratios are equal, each position in one loop having a corresponding equipotential position in the other loop. The two loops need not be the same size, nor have constant section conduit. However, where they are the same size and the conduit is of constant section, the equipotential positions are readily found as they are equidistant from one of the junctions (and hence by symmetry from theotherjunction also).

An alternative is to provide two input transformer cores inductively linked one to the exclusive portion of each loop, the primary windings of the two cores being connected such that when an alternating signal is passed simultaneously through the two windings, the currents induced in the two loops reinforce each other in the common portion.

The output cores may be similarly disposed, i.e. as a single core inductively linked to the common portion of conduit, or as two cores arranged in different loops. The transformer configurations can also be mixed in that where, for example, two input cores are used, one in each loop, separate output cores for each loop or a single common output core, will both work effectively.

With the main flow between the two ports passing through both sides of each exclusive portion, there is a danger of the common portion becoming a dead portion, which is particularly undesirable when input and/or output transformer cores are inductively coupled to that common portion. We therefore prefer to couple the transformer cores to the exclusive portions, and to reduce the length of the common portion to a minimum, e.g. until it is reduced in effect to a port interconnecting two loops formed by the two exclusive portions. An alternative but more complex way of modifying the first species is to provide internal baffles to divide the flow. However, we generally prefer in practice to use one of the following alternative species.

The first of these alternative species (returned to hereinafter as "the second species") is represented by an apparatus having a conduit configuration which looks superficially like the two loops described above, but wherein the conduit is in fact in the form of a single closed loop which has been folded round to pass through the core of the input transformer two or more times in the same direction thereby to form an equal number of open loops, the inlet and outlet ports being located at positions of equal potential in different open loops. If many open loops are formed, difficulty may be experienced in establishing smooth flow through the whole of the closed loop without leaving dead spaces, and to assist flow, positions of equal potential in more than one open loop can be connected to a common inlet or outlet port.However, the simplest form of folded loop is generally preferred, i.e. wherein the single closed loop is folded to pass through the input transformer core twice only, thereby forming two open loops, with an inlet port in one and the outlet port in the other open loop.

A third species, which is particularly preferred for most applications, is one comprising a closed loop of conduit having inlet and outlet ports spaced apart so as to divide the loop into two portions each of which interconnects the two ports, and two input transformer cores inductively linked one to each of the two portions of the loop, the primary windings of the two cores being interconnected so as to induce currents simultaneously in the same direction around the loop. The current induced in any liquid flowing through the loop is preferably detected similarly by two output transformer cores inductively coupled to each portion of the loop. We have found that this system can be operated effectively whether the input and output cores of the two portions are in the same or opposite order around the loop, and whether the windings of like kind are connected in parallel or in series.However, we generally prefer to connect at least the two primary windings in parallel, as we find in practice that this arrangement is less sensitive to differences in conductivity of the two portions.

The apparatus is suitable for measuring the conductivities of a wide range of liquids, liquid mixtures, solutions and even slurries, the indirect induction of current in the liquid avoiding the corrosion, polarisation and solid deposition problems associated with direct contact between electrodes and liquid. Compared with known inductive apparatus as mentioned above, the present apparatus is particularly advantageous for use in applications wherein the ports are necessarily connected to conducting pipework, such as may occur in chemical manufacturing plants. Similar problems may also arise in hospitals and food production, and the present apparatus also provides the same advantages over prior art apparatus in those situations, for essentially the same reasons.

In applications in which the apparatus is required to be inserted into insulating pipework, as frequently happens in laboratory applications, the present invention also provides advantages in that it allows the apparatus to be isolated from any stray currents within the liquid in other parts of the apparatus, which might otherwise affect the measurements obtained. This can be achieved by placing interconnected electrodes in the liquid on either end of the apparatus, so as to bypass the apparatus with a low conductivity shunt. Moreover, the features which distinguish the present apparatus from the known apparatus referred to above and which provide advantages under arduous conditions, in no way inhibit the present invention from measuring conductivity at least as effectively as the aforesaid known apparatus under less arduous conditions.

The invention is illustrated by reference to several specific embodiments shown in the accompanying drawings, in which
Figures 1 to 3 show variations of the first of the above species,
Figure 4 shows an apparatus of the second of the above species and
Figures 5 and 6 show variations of the third of the above species.

The apparatus of Figure 1 comprises insulating conduit of substantially constant cross-sectional area, arranged in the configuration of two closed loops 1, 2, having a portion 3 which is common to both loops, the remaining portions being exclusive. The exclusive portions of both loops are in liquid communication with the common portion through the junctions 4, 5 at both ends of the common portion. In the exclusive portion 1 of one loop, half way between the two junctions is an inlet port 6, and symmetrically placed in the other loop is an outlet port 7.

Mounted on the common portion are two torroidal transformer cores 10,1 one of which carries primary windings 12 connected to an oscillator 13, and the other carries secondary windings 14 connected to an ammeter1 5. The cores are also coupled by a balancing circuit comprising windings 16, 1 7 on the two cores and a variable conductance1 8 to complete a bridge network. The ammeter1 5 incorporates its own rectification and amplification circuitry.

In use the apparatus is connected into a chemical plant line or other ducting system carrying the liquid whose conductivity is required. The liquid enters into the apparatus at the inlet port 6, fills all of the two loops of insulating conduit, and leaves via the outlet port 7. An alternating current is passed through the input windings 12, to induce alternating currents in the liquid in the conduit and also in the windings 1 6 of the balancing circuit. The circuit within the liquid is completed by the two loops 1, 2, and hence a current can flow within the liquid without any need for contact with external means to complete a circuit.Furthermore, in so far as the liquid is homogeneously distributed throughout the conduit configuration, the symmetry of that configuration ensures that whatever potential is induced in the liquid at one port, it will be matched by an equal potential at the other; and accordingly earthed conducting pipework can be used for the plant attached to the ports without affecting the currents induced in the liquid by the input transformer1 0.

The core of the output transformer11 inductively links the liquid circuit and the secondary windings 14, and any current induced in those windings is detected by the ammeter1 5. However in this embodiment the transformers are also coupled by the balancing circuit whose windings 16,1 7 are wound in a direction such that the current induced in the secondary windings 14 by that in the balancing windings1 7 is opposite in direction to that induced by the current in the liquid. The variable conductance1 8 is then adjusted until the ammeter1 5 indicates that there is no resultant current in the output windings.The conductance of the liquid within the apparatus is then equal to that of the variable conductance 18, from which the conductivity of the liquid can be calculated in known manner from the dimensions of the conduit, or by calibration of the apparatus using liquids of known conductivity as standards.

The apparatus shown in Figure 2 uses the same configuration of conduit as that of Figure 1, and like parts have been allocated like reference numerals. However in this apparatus two input transformer cores 20, 21 are provided, one for each loop, and two output transformer cores 22, 23 are similarly deployed. The windings of both pairs of cores are connected in parallel, the primaries to a source 13 of alternating current and the secondaries to an ammeter 1 5. The directions of the windings are such that the currents they induce in the common portion 3, are reinforcing.

The apparatus of Figure 2 is connected to plant pipework in essentially the same way as that of Figure 1, and an alternating current is again provided in the primary windings of the input transformers.

However, as no balancing circuit is provided the current induced in the secondary windings is read directly on the ammeter1 5.

In the apparatus of Figure 3, a pair of input transformer cores 30, 31 are used as in the Figure 2

apparatus, while a single output transformer core 32 similar to that of Figure 1 is employed. Either a direct measurement of induced current may be obtained or a bridge circuit corresponding to that of Figure 1 may be used, with the two input transformers 30, 31 both being linked into the balancing circuit so as to appear effectively as a single input transformer, with the balancing circuit being wound round the output core 32 as before.

With the symmetrical configurations of Figures 1 and 2, one of the difficulties lies in the length of time required to reach equilibrium following a change in composition, due to the poorer flow through the common portion 3. In Figure 3, the inlet 6 and outlet 7 ports are shown displaced in order to illustrate how these may be sited in alternative positions so as to vary the flow through the various parts of the apparatus. These are again equidistant from the junctions of their respective loops, and this symmetry induces equal potentials at the two ports, even though these will generally be different from those induced simultaneously at the port positions illustrated in Figures 1 and 2.

Figures 1 to 3 show just three variations of one of the species referred to in the general description hereinabove. Other variations are also possible, and these three are merely intended as illustrations of one of our preferred species of this invention. Other variations include for example the use of the common transformer core 32 as a single input core while using the pair of cores 30, 31 as twin output cores. A particularly useful alternative is the replacement of the single transformer core 32 by a pair of cores 33, 34 (shown by broken lines in the drawing) in the exclusive portions of the loops. These two cores can be located on the same side of their respective ports as the other cores (as shown) or on opposite sides to give a configuration similar to that shown in Figure 2 (except for the displacement of the ports).

In Figure 4 we turn to a different species of the same invention. Although this is superficially like that shown in Figure 1, the liquid passing through the two transformer cores 40, 41 is in two separate lengths of conduit between which there is no direct fluid communication (i.e. the only fluid interconnection is around the remainder of the loops past one port or the other). The conduit of this apparatus is in the configuration, so that anything (e.g. a current) travelling round the loop will pass through the transformer cores twice in the same direction, and the loops 42, 43 thus formed are open loops.

The input and output transformers may be connected either in a bridge configuration in the manner of Figure 1 or for direct measurement in the manner of Figure 2, and the apparatus is used as described for those other embodiments respectively. The advantage of this second species over the other, however, is that all the liquid has to flow through the transformer cores, and is thus in sharp contrast with the superficially similar configuration shown in Figure 1.

Two further embodiments of the present invention are shown in Figures 5 and 6 as examples of the third species referred to in the general description above, but in effect these are really variations of the embodiment shown in Figure 4. If each of the cores 40, 41 is replaced by two transformer cores moved to the sides of the figure of 8 with only one of the open loops passing through each, i.e. in a manner similar to the change from Figure 1 to Figure 2 arrangement, the closed loop can be unfolded to remove the twist. The result is the arrangement shown in Figures 5 and 6, although as will be appreciated, the electrical connections between the transformers are different, due to the initial twist in the complete loop.

Thus in Figure 5, the conduit is in the form of a single loop having inlet 6 and outlet 7 ports spaced apart so as to divide the loop into two symmetrical portions 50, 51 each of which interconnects the two ports. Each portion of the loop is threaded through the cores of an input transformer and an output transformer. The two input transformers 52, 53 are arranged diagonally across the loop and are provided with a common alternating current from a generator 54. They are connected in parallel and the windings are in the directions in which the currents thereby induced in liquids flowing through the loop, are simultaneously in the same direction around the loop. Thus when the induced current in one of the two portions of the loop is in the same direction as the liquid flow, that in the other portion is opposite to the direction of liquid flow.The two output transformers 55, 56 are similarly arranged diagonally across the loop, and are connected in parallel to an ammeter 57, which measures directly the current induced into the output circuit.

The apparatus of Figure 5 will also operate effectively with the pairs of transformers connected in series rather than in parallel, and this is shown in Figure 6 where like reference numerals have been used for like parts. However, parallel connections are preferred, as then any small inequality in the conductances of liquids in the two portions of the loop appear in practice to be automatically compensated for.

A further change which has been shown in Figure 6, is the positioning of the pairs of transformers in a mirror-image disposition instead of the diagonal disposition of Figure 5. This variation appears in practice to make no change in the conductivity measurements, and like its diagonal counterpart, is preferred with parallel interconnection of transformers rather than the series interconnections shown.

In the drawings, the configurations have been shown opened out for clarity, but in some of these at least, e.g. Figures 1 and 4, it may be more convenient in practice to fold the conduit about the horizontal axis of symmetry (according to the view illustrated) so as to bring the liquid connections all to one end of the apparatus and the electrical connections to the other. Similarly, although the abrupt angles and straight sides to the loops enable them to be readily assembled from standard angle mouldings and tubular extrusions of plastics materials to a variety of configurations, as illustrated, different conduit diameters may be used for different parts, or the sharp angles can be removed (with probable benefit to the liquid flow) by customised curved mouldings as desired, without departing from the broad aspects of the invention.

The invention is illustrated by the following Examples in which Example 1 employs an apparatus according to the. present invention, and Example 2 is comparative, showing the apparatus arranged in known manner. For both Examples, an apparatus wasprepared substantially as shown in Figure 5 except that provision was made for removing an input transformer core from one portion of the conduit loop and an output transformer core from the other portion. The ports were each closed by a plug carrying a stainless steel electrode to simulate stainless steel pipe lines and the apparatus was filled with a molar solution of potassium chloride in water.

EXAMPLE 1
The apparatus was arranged as shown, with two input transformers 52, 53 connected in parallel to the AC signal generator 54, and the two output transformers 55, 56 connected in parallel to the meter 57. With the electrodes disconnected, the conductance was calculated from the meter reading, to be 12.54,uS. The two electrodes were then shorted, and the meter reading remained unchanged.

EXAMPLE 2
The apparatus was then modified by removing one core from each portion as mentioned above, so that there remained an input transformer core around one portion of the loop with an output transformer core around the other, i.e. in the manner of known conductivity cells. With the electrodes disconnected, the conductance was again measured as 12.54yS. However, when these were shorted out, the conductance as measured fell to about 3 yS.

In a chemical plant, it is unlikely that the apparatus would experience a direct short across its ports, although with effective earthing the resistance of any ground loop may indeed be fairly low. In order to investigate the effect of leakage through a resistive ground loop, the electrodes were connected via a resistance box, with the conduit still carrying only a single input transformer core and a single output transformer core. The results obtained where as follows, where the resistance quoted is the value of the resistance box.
EMI5.1

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Apparatus for measuring conductivity

Claims of **GB2093192**

CLAIMS

1. Apparatus for measuring the conductivity of a liquid comprising insulating conduit in the form of one or more closed loops with spaced inlet and outlet ports to enable liquid to flow through the conduit, at least one input transformer core carrying primary windings for receiving alternating current and at least one output transformer core carrying secondary windings, the input and output transformer cores being inductively coupled by the one or more closed loops, and the configuration of the conduit and the positioning of the transformer cores with respect to the inlet and outlet ports being mutually arranged such that when the conduit is full of conducting liquid and an alternating current is applied to the primary windings of the input transformer, the potential thereby induced in the liquid at the inlet port is substantially equal to that induced at the outlet port.

2. Apparatus as claimed in claim 1, wherein the conduit configuration comprises two closed loops, each having a portion common to both loops with the remaining portions exclusive, the exclusive portions being in liquid communication with the common portion through their junctions at both ends of the common portion, the inlet port being in the exclusive portion of one loop and the outlet port being at an equipotential position in the exclusive portion of the other loop.

3. Apparatus as claimed in claim 2, wherein the at least one input transformer core is inductively linked to the common portion of the two loops.

4. Apparatus as claimed in claim 2 having two input transformer cores inductively linked one to the exclusive portion of each loop, the primary windings of the two cores being connected such that when an alternating signal is passed simultaneously through the two windings, the currents induced in the two loops reinforce each other in the common portion.

5. Apparatus as claimed in claim 1 wherein the conduit is in the form of a single closed loop which has been folded round to pass through the core of the input transformer two or more times in the same direction thereby to form an equal number of open loops, the inlet and outlet ports being located at positions of equal potential in different open loops.

6. Apparatus as claimed in claim 5 wherein the single closed loop is folded to pass through the input transformer core twice only, thereby forming two open loops, with an inlet port in one and the outlet port in the other open loop.

7. Apparatus as claimed in claim 1, and comprising a closed loop of conduit having inlet and outlet ports spaced apart so as to divide the loop into two portions each of which interconnects the two ports, and two input transformer cores inductively linked one to each of the two portions of the loop, the primary windings of the two cores being interconnected so as to induce currents simultaneously in the same direction around the loop.

8. Apparatus, as claimed in claim 7 wherein the two primary windings are connected in parallel.

9. Apparatus according to any one of the preceding claims having interconnected electrodes positioned at either end of the apparatus to contact liquid flowing into the inlet port and from the outlet port respectively; thereby electrically to bypass the apparatus with a low conductivity shunt and isolate it from any stray currents elsewhere within the liquid.

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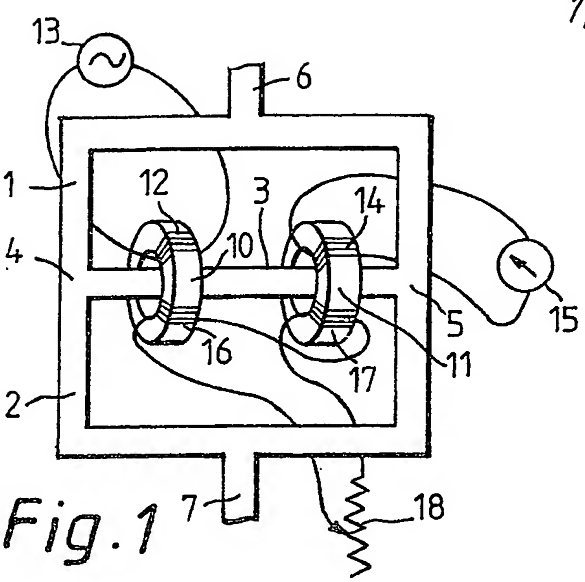

Fig.1

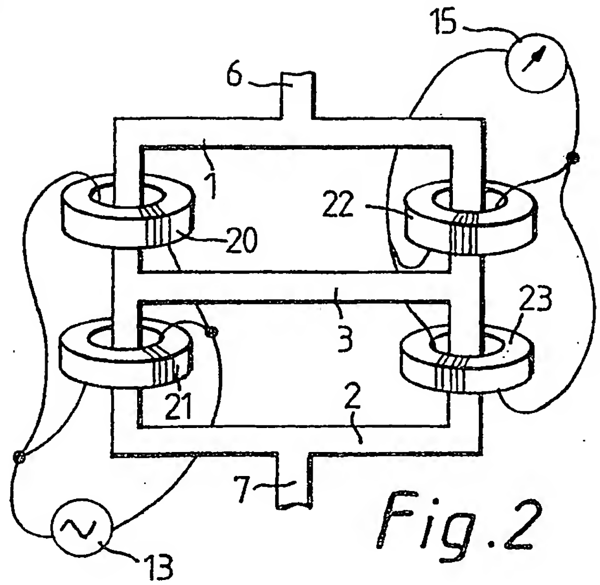

Fig.2

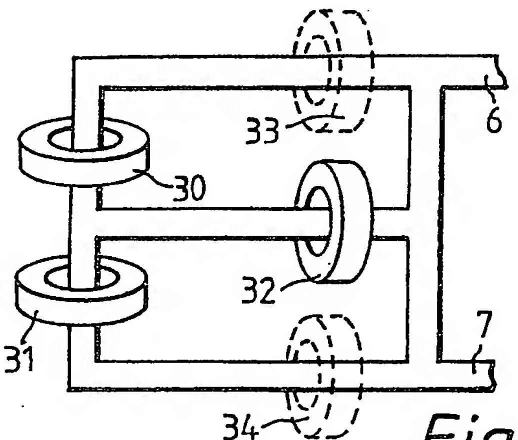

Fig.3

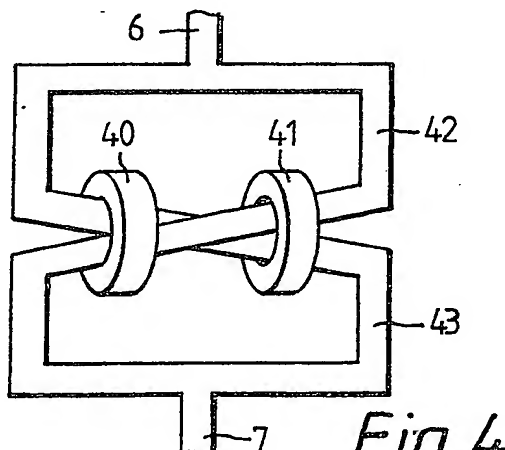

Fig.4

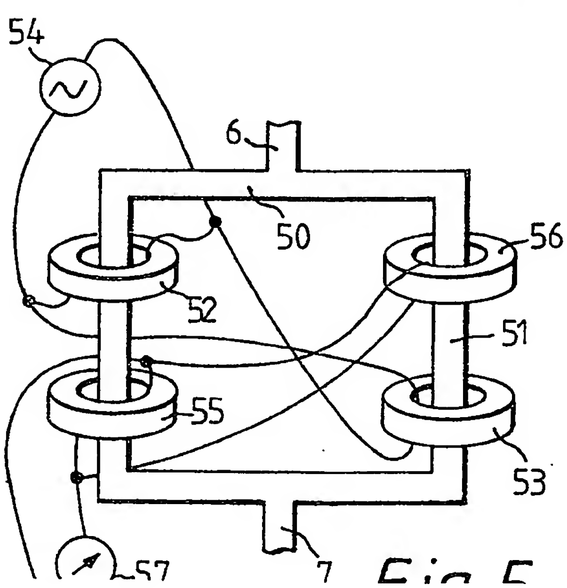

Fig.5

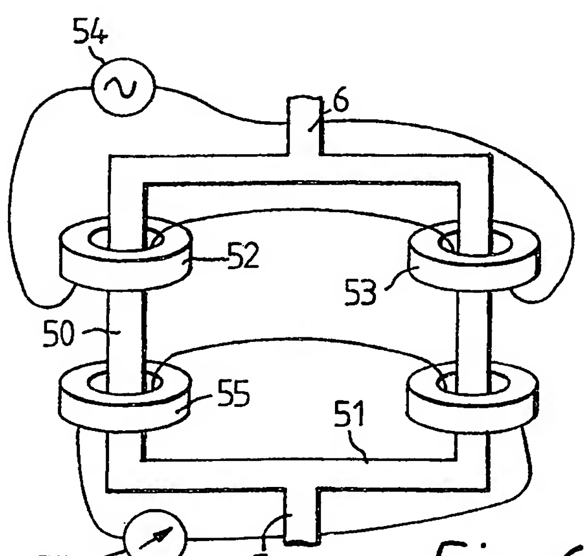

Fig.6